Microwave Engineering education during COVID-19 pandemic: challenges and solutions implemented in practical work

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***Abstract* — This article aims to provide some insight into the educational challenges faced at the University of Limoges during the COVID-19 pandemic. The teaching strategies and resources implemented to ensure the pedagogical continuity of Microwave and Optical Engineering practical work for undergraduate and master students are exhibited.**

***Keywords* — COVID-19, pandemic, Microwave, practical work, distance learning.**

I. Introduction

Since the beginning of the health crisis, the COVID-19 pandemic has largely impacted the education systems, affecting nearly 1.6 billion learners around the world [1]. The necessity to drastically slow down the infection has pushed governments to close educational institutions as a protective measure for the safety of learners and education personnel. Great efforts were made to prevent shocks to education systems, ensure the education continuity and avoid learning losses [2]. Although the crisis created several challenges to be faced [3] it has also stimulated the application of innovative solutions for high quality education within the pedagogical community. With the widespread use of technology, many countries quickly switched to distance learning methods to ensure the continuity of classes during the lockdown. This process brought the opportunity to adjust the contents, to re-evaluate the needs and to enrich the learning experience. Several pedagogical approaches, software tools and learning platforms have been applied in science and engineering courses around the world [3]–[5] and other domains.

At the Faculty of Sciences of the University of Limoges (France), online learning and remote measurement manipulations were previously implemented in e-learning courses [6]. However, this approach has been extended to undergraduate and master degrees related to microwave and optical domains during the pandemic. The previous experience and infrastructure together with the help of the Physics and Information and Communications Technology (ICT) departments allowed a quick response to confront the educational problems to come. The scope of this paper is to present an insight into the challenges and experience obtained at the University of Limoges in Microwave Engineering practical work since the beginning of the pandemic in Europe.

II. Infrastructure and support

Before the health crisis, many lecturers and research teachers of the institution were already trained by the University in the use of online learning platforms. Some of these platforms were also regularly used in the courses as support and communication channels with the students. The closure of educational institutions in France during the first lockdown promoted the migration to a fully online delivery format which led to a great effort to adapt the programmes and the educational structure in a short period of time. A technical and pedagogical unit with experience in distance learning and digital documents/media production was made available. This support unit helped lecturers to develop the necessary abilities for the use of fundamental tools and resources available. This includes handling the teaching platform (Moodle), managing a virtual classroom and recording the lectures (BigBlueButton, Ubicast, Powerpoint, Audacit), access the application servers and creating media resources such as audio and video. The increment of multiple users simultaneously connected to attend the lectures was a challenge for technical support to properly administrate the resources, enhance the server infrastructure and improve the network speed. Moreover, the ICT department provided a continuous online support service to solve problems related to internet access, server connection, equipment and materials. The preparation of fixed test-benches connected to the already-in-use infrastructure

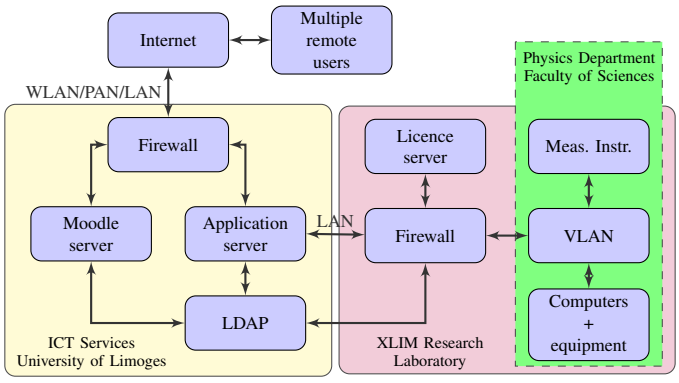

Fig. 1. University of Limoges: services and network infrastructure map.

[6] available at the faculty research laboratories helped to overcome the problem linked to face-to-face practical work. Fig. 1 shows the overall architecture of the network. The setups were prepared beforehand by the teachers and assistant professors with the required material for every lesson. The measurement equipment was interconnected to the laboratory VLAN and accessible remotely via VPN or clientless remote desktop gateway (Guacamole server). A reservation system was available in Moodle for the students to reserve the test-benches to perform the practical work from home. A dedicated Microsoft Windows server was installed with the required software for Microwave technology learning: circuit, electromagnetic and multiphysics simulators (ADS, HFSS, CST and Comsol), transmission line calculators (LineCalc) and measurement equipment software for remote control. The server was available for both teachers and students through the VPN of the university. A more detailed analysis about the different practical work and test-benches implemented during the pandemic will be presented in the next sections.

III. E-LEARNING IN MICROWAVE PRACTICAL WORK

The closure of the university laboratories had a strong impact in Microwave Engineering practical work where measurements and equipment manipulation is of great importance. The practical work was adapted to the available laboratory infrastructure and focused on the most relevant devices studied in the theory. The equipment handling training was changed to a remote autonomous modality without the need for regular setup assemblies. The approach adopted allowed the students to keep the continuity of practical work, perform measurements at a distance from a secure environment and maintain the interaction with the teachers. The test-benches were prepared by the staff beforehand depending on the schedule. The mounting and calibration process was recorded on video and uploaded to the teaching platforms together with the calibration files to be used by the students. The contemplated experiences comprehended the emulation of device measurements (measurement pre-saved in memory) and real time measurements of multiple ports RF devices with a Vector Network Analyser (VNA). The main objective of this approach was to train the students in the manipulation of RF instruments (learning the menu settings, markers and typical parameters), to understand the importance of instrument calibration, to exercise the interpretation of measurements and relate them to the theory.

A. *Passive filters measurement emulation*

In order to introduce the fundamentals of S-parameter measurements, a setup compound of a VNA connected to the VLAN network was prepared in the university laboratories. Some manufacturers such as Copper Mountain Technologies provide free installation software (TR VNA) for multiple-user VNA control and local measurement data storage. The graphical user interface (GUI) of the software reproduces the instrument panel screen facilitating the simultaneous interaction and guidance between students and teachers.

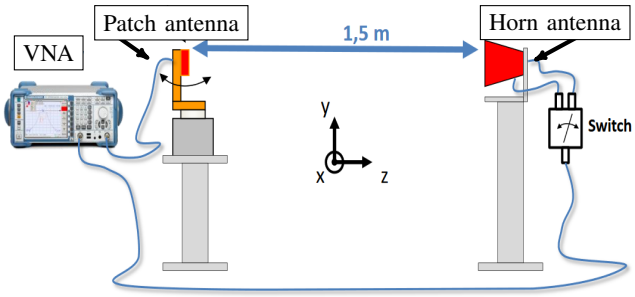

Fig. 2. Patch antenna characterization test-bench.

Additionally, the VNA provided by this company contains a very realistic filter measurement emulation mode using pre-saved data in the instrument internal memory. This was an interesting feature in the context of the pandemic for the analysis of typical multi-resonator band-pass filter characteristics (e.g. central frequency, bandwidth, number of poles and insertion losses) without the need of a real device connected to the equipment. The import of real measurement files is also possible with this test-bench.

B. *Real-time measurements*

A specific setup was prepared for real-time measurement practical work composed of a Keysight VNA (E5063A – 18 GHz) calibrated by the teachers and connected to the laboratory network. The calibration files were available in the respective course learning platform for their utilization during the practical work. The first activity proposed consisted in the characterization of a circulator at 5 GHz, a complete analysis of the non-reciprocal conditions, the composition of the measured hexapole, comparisons related to commercial specifications (operating band, matching, insertion losses and isolation) and final conclusions on behaviour. A second test-bench was prepared for the experimental characterization of planar antennas on printed circuit boards (PCB). Remote real-time measurements were possible for this experience thanks to the setup illustrated in fig. 2. The setup consisted of a reference horn antenna placed at an appropriate distance to ensure the far field condition, and an antenna under test (patch antenna) fixed to a mobile support. Each antenna was connected to a Rohde & Schwarz ZVL VNA channel for S-parameters analysis between 9 KHz and 3GHz. A previous calibration process was performed in order to de-embed the elements up to the antenna interface. The antennas utilized for this practical work were fabricated at the facilities of the university. As in the case of the circulator, the activity consisted in the characterization of the typical antenna parameters (input impedance, matching and resonant mode frequencies, gain and 3 dB beamwidth).

C. *Real-time and imported measurements*

The main purpose of this practical work was to determine experimentally the resonance frequency and the loaded quality factor (Qo) of a cylindrical metal cavity, and establish their dependence on the cavity dimensions. The structure consisted

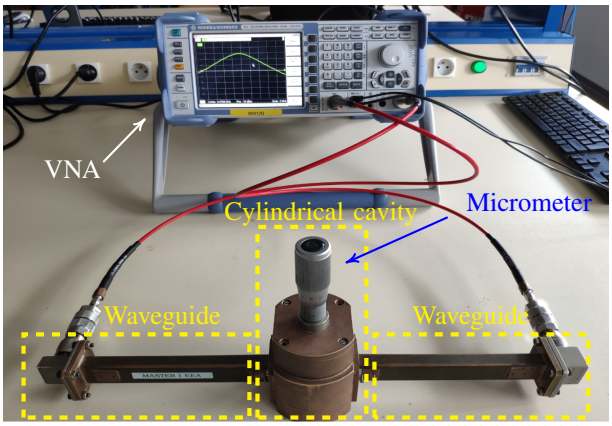

Fig. 3. Cylindrical resonant cavity test-bench.

of a fixed part (bottom and side walls) and a mobile part (top wall) linked to a micrometer (fig. 3). The characterization of the cavity was performed by the students with a Rohde & Schwarz ZVL VNA connected to the device under test up to 13 GHz. The test-bench was set in the laboratory and the micrometer position modifications of the cavity top wall were performed by the assistant professor with the online interaction of the groups. In this practical work, both real-time (cavity) and pre-saved measurements (accesses) were utilized by the students to remove the effect of the excitation waveguides and correct the measurements. The waveguides were measured before the practical work by the teachers and stored in the VNA memory to be accessed during the lesson. With this information it was possible for the students to estimate the external quality factor (Qe) and the unloaded quality factor (Qo) of the device under test.

IV. Signal Processing Practical Work

Unlike microwave practical work, the application server was already prepared for signal and data processing practical work related to time and frequency domains. The challenges faced during the pandemic were linked to the interaction with the students at a distance. All the lessons were transferred to a virtual classroom (BigBlueButton) integrated to the Moodle platform. An alternative external connection was also available to avoid server overloads. Multimedia resources such as audio, video, screen sharing and uploading of presentations were available, thus enhancing the experience and facilitating the communication with the students. At the beginning of the lockdown, a special two hour session was performed with the students to verify the correct operation of the VPN connection, server access, and virtual classroom handling. As a result, problems related to the difficulties of multiple webcam streaming were addressed. Nevertheless, the students were still able to do collaborative work among themselves.

During the practical work sessions the students were able to access the teacher explanations, access and utilize simultaneously the available softwares in the application server and interact with the class to perform the activities. Furthermore, during the practical work the students were asked

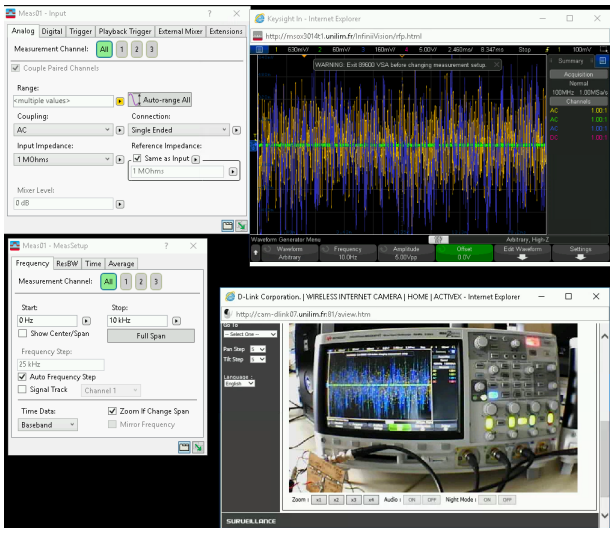

Fig. 4. Remote oscilloscope measurements with VSA 89600 B GUI and webcam surveillance.

to answer questions, share their screens and remote desktops, and comment or give conclusions of their results.

A. Numerical analysis programming

Four numerical analysis programming practical work were carried out in eight lessons of four hours each. The courses were subdivided into two groups to avoid excessive data traffic and multiple licence requirements. The objective was to implement numerical approximation algorithms for mathematical problem solving in digital environments. During this course, the analysis was applied to signal processing of real microwave measurements. In this modality, the teachers and students were connected to the virtual classroom and the application servers in order to follow the explanations and perform the activities at the same time. The students interacted to implement with MATLAB the mathematical strategies studied in the theory, and discuss the advantages and drawbacks of the different suggested methods. In the case of difficulties to access the application server, the students were asked to use MATLAB online, Octave or Scilab on their local computers. The proper functioning of the virtual classroom was a critical for the class to be able to exchange opinions and results. Besides, the performances evaluation (in terms of time and computational resources) of numerical integral calculation scripts, equation system solvers or measured data interpolation, in a server with multiple users, brought deeper discussions to the practical work.

B. Time and Frequency Domain Instrumentation

Electronic circuits as digital adders and sample and hold ADCs were used to introduce the fundamentals of data acquisition in time and frequency domain with oscilloscopes. In these practical work, the students were trained in the use of typical oscilloscope parameters (e.g. menu settings, markers and specific features), remote equipment control, transfer and data process with VSA 89600 B professional software

(fig. 4). The theoretical concepts of periodic and aperiodic deterministic signal spectrum, auto- and inter-correlations, deterministic and random noise signal power, signal-to-noise ratio and basics of digital modulations were implemented with the measured data. Before the lockdown, two practical sessions were already carried out with the use of LAB-EN-VI [6] at the faculty laboratories. Each practical work session was duplicated in several sessions to subdivide the courses in groups of three students and every group was managed by a teacher. Teachers were equipped with a tablet with a PDF Annotator, and a Bluetooth conferencing terminal (microphone and speaker) as replacement for the typical whiteboard. Moreover, twelve oscilloscopes connected to the devices under test were available for measurements twenty-four hours a day, seven days a week. Furthermore, twelve webcams were installed in the test-benches for visual verification during the measurements (fig. 4). Finally, every lesson was completely or partially recorded in BigBlueButton and uploaded to Moodle as pedagogical material for the students.

C. Measurements Automation

The LAB-EN-VI infrastructure was also utilized in Master 1 courses for two LabView practical work by Ethernet-GPIB connection: automation of a base-band radar detection bench and automation of a GaAs transistor for I/V curves measurement. The setups were based on four oscilloscopes, four programmable DC sources and multimeters with GPIB connection. The software and licences were installed in the application server accessible via VPN. The amount of practical work were reduced and performed during a whole day. However, the pedagogical methodology was not significantly modified due to the previous characteristic of distance learning for foreign students of this master. The practical work was adapted to ensure the minimum modification for in-person students using the experience obtained in other subjects.

V. Survey and evaluation methods

The student progress was continuously evaluated during the classes held in lockdown. Some utilized strategies were the modification of the measurement conditions by the examiners during the practical work, the demand of reports, and interactive multiple-choice tests in Moodle. The synergy generated thanks to the continuous interaction of the students in virtual classrooms, by sharing their results or their experience during the practical work had a positive impact on the learning process. Multiple-choice tests were available on the platform a few hours before, with the same exercises to be solved but with random values within a range coherent with measurement tolerances. The tests were integrated with interactive graphical interfaces developed in Javascript by the teachers. The students had the possibility to choose a date in a Moodle calendar and reserve the equipment to perform the practical work. Furthermore, half a day was set between the end of the course and the date of reports submission for online questions (20 minute slots). In the case of data acquisition practical work, the evaluations consisted of a 30 minutes oral test per student via BigBlueButton. The students were asked about five different topics on the aspects related to instruments configuration and manipulation.

VI. Conclusion

The benefit of the infrastructure and the resources re-implementation associated to LAB-EN-VI together with the experience of the University ICT department led to a fast response to face the educational challenges generated as a consequence of the COVID-19 pandemic. Almost 75% of the lessons planned for the semester were accomplished. Moreover, 50 to 80% of the practical work was completed depending on the available time and resources. This was possible thanks to the pedagogical surveillance policy adopted and the well equipped laboratories of the faculty. The formation of support teams experienced in the use of online platforms and ICT tools were essential to introduce new communication and learning methods to teachers and students. The data obtained during online measurements was complemented with the analysis, interpretation and comparison of the theory. The application of quick quizzes at the end of the class is suggested as an improvement to evaluate the understanding of the fundamental concepts studied during the day. The permanent accessibility to the measurement test-benches was a strong point in comparison to the previous in-person modality, allowing the students to redo measurements, consolidate the knowledge, and use the virtual classroom forum to ask questions. The infrastructure improvements and the gained experience was not only useful to ensure the continuity of classes during the pandemic, but also to enhance the in-person practical work experience at the end of the lockdown. According to a survey conducted at the end of the school year, 88% of the students believe that they have been partially to moderately affected in the learning process during the pandemic and 78% agree that the implemented strategies should be maintained as part of the regular courses.

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